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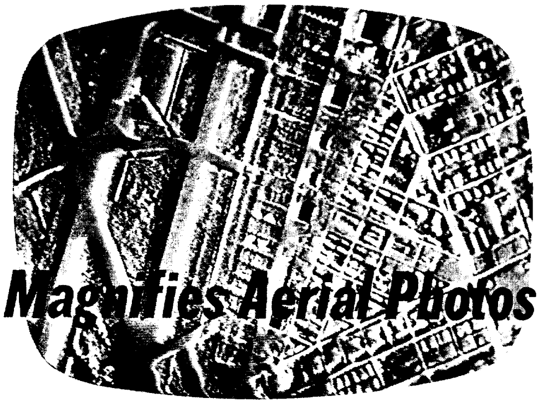
Precision optical viewers provide high resolution over a large subject area. But they are costly, complex and inflexible when compared to this high-magnification electronic viewer. It offers rapid, remote-control display and also permits image enhancement.

Zoom Viewer Magnifies Aerial Photos Electronically



Display from electronic film viewer shown with both negative and differentiator controls energized.

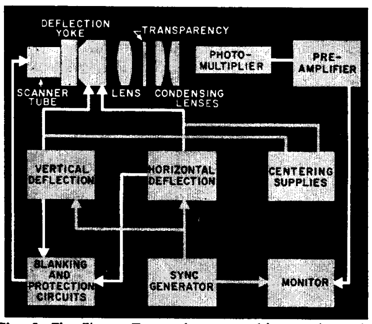


Fig. 1. The Electro-Zoom viewer provides continuously variable, in-focus system magnification of a 70-mm transparency between 7 and 150 times. Further step magnification up to 380 times is possible when viewed on a 24-in. monitor. The limit of resolution is better than 50 optical lines per millimeter at magnification factors of 150 or more. A flying-spot scanner is used as the image transducer. This relatively old and simple technique converts a three dimensional scene—*X, Y, I* (intensity)—into a two-dimensional (*I, t*) time sequential video signal. A lens focuses the raster on the transparency with the photo-multiplier directly behind the film holder.

Jacob L. Breitbord
John Main
Itek Corp.
Lexington, Mass.

A NEW and inexpensive electronic film viewer simplifies interpretation of aerial and space-satellite reconnaissance photographs. The system offers many advantages over more expensive and complex optical viewers. Among them are:

- Large screen display.
- Multiple viewing at remote locations.
- High magnification with minimum transmission of energy through the film (particularly important in satellite photography).
- Ability to repeatedly view first-generation film without danger of loss or physical damage.
- Full choice of positive or negative viewing.
- Real-time video processing.
- Availability of image enhancement techniques.

Except for the scanner tube and power supplies, the system consists entirely of commercially available television components. It uses a magnification system that combines optical minification and shrinking raster techniques to provide apparent resolution of up to 50 optical lines per millimeter at magnification of up to 380 diameters.

By packing the relatively few active lines generated by commercial television into a small dimension, and by selecting scanner systems, optics and film with the required transfer characteristics, it becomes possible to increase apparent, or usable, resolution by a big factor.

Looked at in another way, the total number of active lines remains constant, but the number of lines in a small increment on the transparency can be increased by an order of magnitude.

Electronic 'Zoom' Control Allows Variable Magnification

The viewer provides a relatively smooth electronic magnification without defocusing. The technique used is termed "electronic

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zoom" because the enlargement of the image resembles that obtained with zoom lens systems.

The active vertical scanner lines are placed closer together until they overlap and are no longer resolvable on the face of the scanner tube, thus filling in the dead space. Writing speed in the horizontal direction decreases as the raster is shrunk, and bandwidth requirements are correspondingly reduced.

A smooth, approximately 4-time magnification range is obtained in this manner. Within this range, the smaller the line width produced on the scanner tube, the larger the magnification, and the greater the resolution available to the viewer.

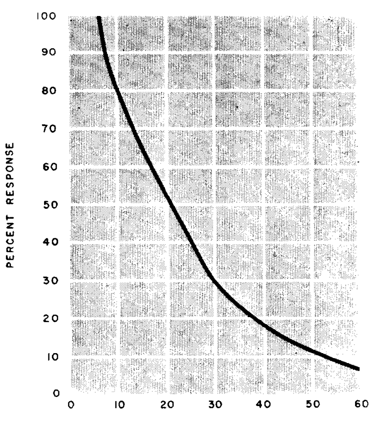

Fig. 2. The original scene is displayed undistorted when the same sweep-wave forms, identically timed, cause the electron beams of the scanner tube and the display tube to be slaved together. The video signal coincidentally modulates the intensity of the display tube. Here is the system square-wave response.

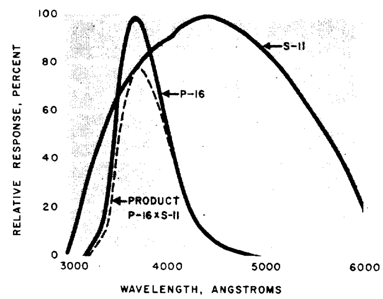

Fig. 3. The scanner tube used in the Itek Electro-Zoom Viewer is a Westinghouse 5CE P16 cathode-ray tube. Spectral response of the phosphor is shown here. A P16 (short persistence) phosphor is used on the scanner tube-face. The light output from this phosphor decays to 10 per cent of its initial brightness within 0.15 μsec. Using a shrinking raster technique and normalizing, a line width of less than 0.00175 in. is measured for the tube. The beam is electromagnetically deflected and electrostatically focused. The face plate is optically flat and non-browning. Final anode voltage is 20 Kv.

The zoom control shrinks the raster linearly in both horizontal and vertical directions by decreasing the drive to the respective deflection yokes. A 3 x 4 aspect ratio is held within 10 per cent at maximum raster size, and to better than 3 per cent at minimum raster size. Horizontal linearity is very good.

The saw-tooth of current through the yoke, and the resultant linearity on the scanner tube-face as displayed by a vertical bar pattern, is well within 5 per cent. In the vertical, the sawtooth of current through the yoke is linear well within a 5 per cent tolerance. The shrunken raster can be positioned over the face of the scanner tube to approximately ± 0.5 in. in the horizontal, and ± 0.7 in. in the vertical.

Several fixed stages of magnification, in addition to the continuously variable zoom control, are provided, for a total electronic magnification of 12.

Photomultiplier Is Used As Light Transducer

An RCA 6199 multiplier phototube is used as the light transducer. This is a head-on, 10-stage photomultiplier having an S-11 spectral response (Fig. 3). In a laboratory mock-up, it was shielded from stray magnetic fields by two layers of shielding material—Mu-metal and Conetic. The shielding was tested by holding a permanent magnet with a strength of 500 Gauss in contact with the shield close to the photocathode. Motion of the magnet had no visual effect on the video output.

The shield is grounded for additional electrostatic shielding; and sufficient space and insulation are provided between the shield and the glass bulb to prevent internal discharge, which creates large noise spikes.

The dark-current signal (no incident light on the photocathode) of the combination photomultiplier and preamplifier is less than 0.3 mv at the cathode-follower output. Light-shielding structures minimize stray light from external sources as well as scattered light from the scanner tube; this keeps noise to an acceptable level.

In order to decrease noise in the signal by

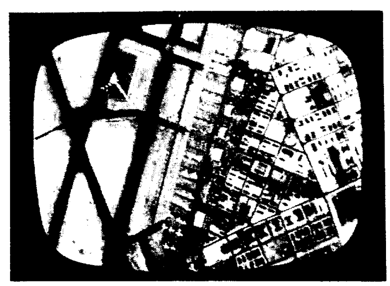

Fig. 4. Display with normal raster on scanner tube.

a factor of four dynode supply voltage was decreased from 1100 to 900 volts. Beam current of the scanner tube was then increased by a factor of 15 to compensate for the loss in sensitivity.

A Conrac CGB-24 monitor (24-in.-diagonal) serves as a primary display; but the system is designed to incorporate many different models of standard television monitors. Displays 10 to 24 in. on the diagonal are available for direct viewing. Projection-type TV viewers can also be used in the system.

Linearity, contrast and brightness of the CGB-24 are more than adequate for system

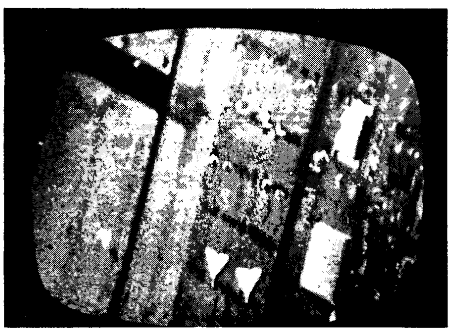

Fig. 5. Display with zoom control energized, resulting in a shrunken raster on the scanner tube.

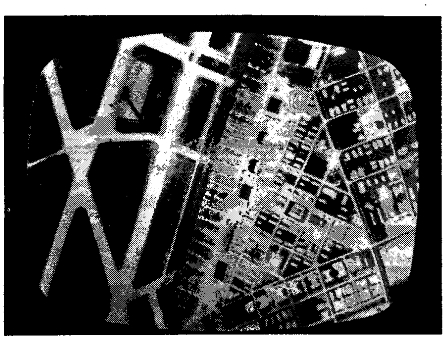

Fig. 6. Incorporation of video processing increases flexibility for the photointerpreter. A two-position switch shifts a positive display to a negative display. This provides video from the plate of the output tube, which is 180 degrees out of phase with the polarity of the signal from the photomultiplier output (negative video). Here is the display with the negative control energized.

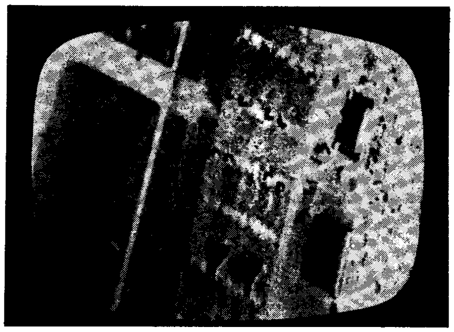

Fig. 7. Display with both negative and zoom controls energized.

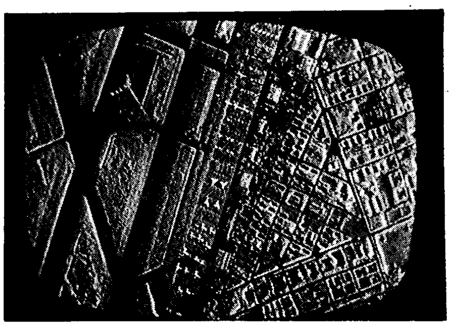

Fig. 8. A simple differentiating network also is incorporated to provide a three-dimensional, bas-relief display. A very short RC-time constant is inserted in the video line. This network attenuates the low frequencies drastically, but provides an increasing response to the high frequencies. As a result, only the sharp transitions appear on the face of the monitor tube. The nonlinear phase function of this simple differentiator creates the three-dimensional effect shown here.

requirements. Bandwidth specifications of ± 1 db at 10 mc have been verified by laboratory tests.

The Blonder-Tongue Labs, Inc., TVC-1B-CG is used as the synchronizing pulse (sync) generator. It is a relatively simple and inexpensive unit. The horizontal sync pulses are generated by a 15,750-cps oscillator, which can be phase-locked to a 60-cps power line. The vertical sync pulses are obtained by multiplying the horizontal by a factor of two to 31,500 cps; then counting down by factors of 3, 5, 7, and 5, to 60 pulses per second. ■ ■

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HUMAN FACTORS ASPECTS OF
PHOTO INTERPRETATION

by

[redacted] STAT

December 15, 1965 - March 15, 1966

[redacted] STAT

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HUMAN FACTORS ASPECTS OF PHOTO INTERPRETATION

1. INTRODUCTION

During the reporting period, efforts were directed toward extracting limited and specific areas of concentration from a vast quantity of publications on the broad and general subject called "vision." This winnowing process still leaves numerous areas of interest, so a shotgun approach has been taken to discuss many of these points. It is hoped that through better understanding of the psychophysical process of the visual system of the human observer, the photo interpreter can be aided in his vital task of reconnaissance and intelligence.

2. PROJECT ORGANIZATION AND PERSONNEL

The project continues under the direction of [redacted] STAT During the month of November 1965, [redacted] became principal STAT investigator succeeding [redacted] STAT Since that time, the program monitor visited the [redacted] STAT facility on two occasions to discuss and define some fields of interest. These areas of investigation included the compilation of lists of institutions, organizations or industries involved in visual programs which might be applicable to the photo-interpretation problem, display screen format, visual acuity, stereoscopy, flicker, and color vision.

3. AREAS OF INVESTIGATION

As a first attempt to indicate organizations and individuals involved in vision research, a membership list of the Armed Forces National Research Coucil Committee on Vision is included as Appendix A. The specialties or fields of interest of many of the individuals, along with their professional addresses, are included. Because of the very nature of this committee and its association with the Armed Forces, it appears that this list could provide a useful starting point. It is by no means complete, and this will be evident in an extensive listing of bibliographies which will appear in a subsequent report.

The areas of investigation covered below in this report include visual acuity (and factors which influence acuity), viewing screen "dither," error keys and the effects of prior knowledge, and display formats. The first section is a brief introduction relating the human eye and visual system to a servomechanism.

3.1 The Visual System as a Servomechanism

The analogy between the human visual system and a photographic or television camera has often been made. There are, of course, obvious similarities but the analogy soon breaksdown. More recently, D. H. Fender (Ref. 1) likens the eye and visual system to a servomechanism which appears to be a much more accurate description. The eye as a servomechanism acts as a device that controls variable physical quantities by comparing actual values with a desired reference value, using differences to adjust the variable.

Continuing the analogy, Fender notes that the cone cells are most closely packed in the fovea - the region of sharpest vision. For close examination, the eyes move so that the image falls on the corresponding areas of the two foveas. Each of the three pair of rotating muscles receives signals proportional to the displacement of the image from the fovea. Another control system brings the eyes to the correct angle of convergence, while still another adjusts the focus by changing the shape (and therefore the focal length) of the lens. This adjustment in focus - accommodation - is not "calculated" from the angle of convergence but instead is achieved by a steady "hunting" mechanism - like focusing a projector lens by hand until accommodation has been steered to the sharpest focus.

Convergence and accommodation mechanisms are separate but cross-linked. Information derived by one is fed to the other, for example, information in sharpest focus is fed across to the convergence mechanism. Another feedback mechanism changes the diameter of the pupil and is linked to the accommodative system because an increase in focal length requires an enlarged pupil to keep the image brightness constant.

3.2 Visual Acuity

Visual acuity is, strictly speaking, the reciprocal of the visual angle, α, subtended by the critical detail of a test object, where α is expressed in minutes of visual angle. As this spatial resolving capacity increases, that is the ability to discriminate fine detail increases, acuity, $1/\alpha$, increases and the visual angle, α, decreases. The terms acuity and resolution are generally used interchangeably and involve the discrimination of two objects versus one. Detection, on the other hand, involves discerning between one object versus none. A fourth term, recognition, is more closely related to resolution, and involves a more specific categorization than just detection.

Boynton and Bush (Ref. 2) state that detection occurs when an observer identifies an object of interest but can't categorize it further. Recognition occurs when an observer identifies an object as belonging to a particular class of objects or as having particular attributes. This can be broken down into increasingly specific categories. Recognition implies prior experience since an observer cannot categorize a completely novel object. Boynton and Bush indicated that in their experiments they were unable to obtain evidence of detection without recognition for the types of targets used. However, in examining, say, an aerial photograph, resolution of two or more objects can occur without recognition of a specific category.

The limiting angular resolution of a typical human eye is generally taken to be about 1 minute of arc. This amounts to a linear retinal image of about 5 microns which corresponds to roughly 10 lines/mm at a reasonably comfortable viewing distance of about 13 inches. This resolution value is by no means constant and is in fact a function of a number of variables. The eye is capable of very high vernier acuity, that is, resolution of the offset between two straight edges placed end-to-end. For this type of resolution test, the visual angle can be as small as about 7 seconds of arc before the offset can no longer be seen. This angle is about one-third the angular subtense of a single cone receptor. Wires having a subtense only one-fortieth of a single cone can be detected under ideal circumstances.

3.2.1 Factors affecting visual acuity

3.2.1.1 Luminance

As the luminance level of a target increases, visual acuity also increases. Starting with the absolute threshold, visual acuity increases and begins to level off when, at the scotopic-photopic (rod-cone) break, acuity increases again and more or less levels off at about normal room luminances. It has been noted that contrast discrimination also improves in much the same fashion as acuity with increasing luminance, and that the two may be related. While acuity is measured in terms of a spatial threshold, and contrast discrimination in terms of a sensitivity threshold, it appears that acuity is a special form of luminance discrimination (Ref. 3).

3.2.1.2 Contrast

At a given luminance level, the higher the contrast the higher the acuity. Conversely, as the contrast approaches zero, the separation between two objects must be increased to be resolved. The minimum contrast for detection between a target and its background is often taken to be about 2 percent, but again this is only a very rough rule of thumb.

The luminance differences of a ground scene, photographed from high altitudes, are generally quite small because of the contrast reducing effects of the atmosphere. These effects can be minimized through the proper selection of filters to attenuate the bluish veiling glare of atmospherically scattered light, and by selection of film which can be processed to a relatively high gamma (contrast).

If the spectral characteristics of a target complex and its background are sufficiently well known, or can be guessed at with reasonable accuracy, film-filter combinations can sometimes be chosen to provide the photo interpreter a photograph with maximum target contrast. Unfortunately, more often than not, target signatures are usually only very roughly known and, except for some experimental situations, the majority of reconnaissance missions using panchromatic film rely almost exclusively on minus-blue filters, and these for their reduction of the effects of haze.

The function of edge gradients can be included in a section on contrast. A number of people (probably starting with Mach in the 19th century) have observed that perceived contrast is "formed over the boundary of an object," (Refs. 4, 5, 6) that is, the spatial-luminance transition connecting adjacent areas. If the gradient at the boundary of two different luminance areas is shallow enough, these differences may not be detectable even if the contrast is well above threshold. This phenomenon has led to the development of many optical and electro-optical systems in an effort to enhance these edge gradients in a photograph.

The human eye apparently performs an edge-enhancement function. The retinal image of a sharply defined bipartite object field is a more or less Gaussian distribution of energy. This image spreading is caused by a number of things, including diffraction by the pupil, spherical and chromatic aberration, scattered light and eye movements. Still, the edge-gradient can be perceived as being very sharp. Mach first suggested that this perceptual effect could be described by a second derivative correction applied to the retinal image, and it is this type of function which is usually performed in optical and electro-optical image-enhancement equipment.

If images are blurred and have significantly reduced edge-gradients, search time increases, the duration of the visual fixations increases, and the distance between fixations decreases (Ref. 5). This is an area where, under some circumstances, contrast and image recognition can be improved dramatically. Yet, while there are numerous contrast-enhancement devices, most of them being experimental, it has been pointed out (Ref. 7) that optical enhancement should probably be left to the interpreter's discretion.

3.2.1.3 Adaptation

Acuity is highest where the fovea is adapted to the level of luminance of the target. In general, acuity is optimized when the surrounding room luminance is the same as that of the target (Refs. 8, 9). There is some degradation when the surround is darker, and even more degradation when the surround is brighter. As a practical matter for viewing images on a front or rear-projection screen, room illumination should be somewhat subdued to prevent stray light from reflecting from the screen, thereby reducing contrast.

3.2.1.4 Wavelength

The visual system, when daylight adapted, has maximum sensitivity to green light at a wavelength of about 555 $m\mu$. The dark adapted eye is most sensitive to blue-green light near 510 $m\mu$. This change in sensitivity between the photopic and scotopic modes is known as the Purkinje shift.

The optical system of the eye suffers from chromatic aberration, yet black-and-white objects do not in general appear to be fringed with color. This may be partially explained by the sensitivity of the eye which tends to ignore the fringes which actually do exist in the retinal image.

There is not a great deal of difference in visual acuity over a broad band of wavelengths, providing the luminance at each wavelength is optimized. Generally, in viewing images in filtered light, there is so little available blue light energy, and the sensitivity to blue is so low, that visual acuity is degraded. Where enough blue light, or red light, for that matter, is available, acuity is about the same as it is for yellow-green light.

3.2.1.5 Optical variables

As mentioned in the section on contrast, the retinal image is affected by diffraction, spherical and chromatic aberration, astigmatism, stray light, hyperopia and myopia (far-sightedness and near-sightedness). If the pupil is very small, that is, about 2 mm, diffraction effects in the normal eye are the limiting factors for acuity. When the pupil is wide open at 7 or 8 mm, the aberration effects contribute most to image degradation. Optimum acuity occurs when the pupil is about 4 mm in diameter, and gets worse on each side of this value. The pupil seems to be set, at a given luminance value, for just the right aperture to give maximum acuity.

3.1.1.6 Eye movements

There have been numerous attempts to correlate the apparent sharpening of a diffuse image falling on a relatively coarse mosaic of cones with the observation that the eyes are constantly in motion. There are low amplitude motions which range from about 30 cps to 70 cps. On top of this are slow motions of irregular frequency and extent, coupled with slow drifts and so-called saccadic jerks at irregular intervals. It can be shown, as in the section below on "screen dither," that an image on a coarse mosaic can indeed be sharpened if the mosaic is moved about. However, in the case of eye movements, there appears to be increasing evidence that visual acuity is as good as it is in spite of eye movements, not because of them. The eye movements tend to keep the image from fading, for the neural system throughout the body is most sensitive to changes or differences.

3.3 Screen Dither

It is, by now, fairly well known that an image, which has been projected onto a coarse surface or viewing screen such as ground glass, can be sharpened by moving the screen about in the plane of the image. The coarser the screen, the more dramatic the improvement. The image is integrated in time and undergoes a sort of statistical smoothing function which sharpens the image.

An example of the effects of screen motion is shown in Figure 1. The top picture is simply an aerial image as seen through a microscope and photographed by a camera attached to the eyepiece. The second photograph was obtained by projecting the resolution target onto a metal capstan roller and photographing the light scattered from the roller. This photo shows the grainy structure of the roller, and the reduced resolution. The bottom photo is similar except that in this case the roller is spinning during photography. The difference is quite evident.

There are screens, such as the Polacoat LS60G material, available which are capable of resolving upwards of 60 lines/mm. With this type of screen, there is little improvement in image quality of high-contrast targets when the screen is dithered, but there is significant low contrast improvement. Since areas of interest in an aerial photo are so often low contrast, screen dither may be of considerable value in improving the perception of this kind of detail.

McLachlan and Adams, in a letter to the editor of the Journal of the Optical Society of America, have also illustrated the effects of moving screens. A copy of this publication is included in this report. Also included is a copy of a patent issued in 1965 to G. Parenti describing a mechanism to move a viewing screen for increased resolution, and an abstract of a paper by Carpenter on "Granularity of Rear-Projection Screens."

3.4 Error Keys and the Effect of Prior Information on Photo Interpretation

Various researchers (Refs. 10, 11, 12) have pointed out the importance of a photo-interpreter's prior knowledge in determining the probability of detecting or recognizing a particular target. This probability depends, in part, on his expectancies, that is, if he has been told to expect a certain target. If an interpreter has been furnished with additional intelligence he is much more likely to find a particular target. He is also more likely to "invent" targets, that is, report targets which are not actually there at all. It has also been shown that there are significant effects due to the interference of erroneous information. An interpreter who has been given false information is often seriously hampered in his search and detection capability.

Martinek and Sadacca (Ref. 13) designed "error keys" and "rights keys" to aid in image identification. The error key was designed to help interpreters avoid common misidentifications. This key resulted in a substantial decrease in the numer of errors, with an attendent increase in accuracy, but no difference in the number of correct identifications. The rights key was produced by presenting photographs of the same quality and scale, taken over the same type of terrain, as the photos to be interpreted. This key, it was reported, had no significant effect on any aspect of performance measured.

3.5 Display Format and Search Procedure

Work performed by Reilly and Teichner (Ref. 14) indicated that a square field of view is generally superior to round ones for target detection. This indeed is fortunate because aerial photography formats are almost exclusively square or rectangular. Screens in viewers are often made about 20" by 30" or 30" by 30", which provides a single interpreter a fairly comfortable viewing field.

If a screen is made too small, concentration of area in the center increases, durations of fixation increase, interfixation distances decrease, and overall search efficiency decreases (Ref. 15). Even with so-called "optimum" screen sizes, however, an interpreter tends to make a quick scan throughout the field and then spend an increasingly greater amount of time concentrating on the center.

While this concentration on the central part of the screen may be partly due to a natural tendency to look more or less straight ahead at a viewing screen, the fact that the image quality is usually better at the center of the format may also play a role. The image quality at the edge of an aerial photograph is almost invariably worse than at the center because of aberrations in the camera lens. These same afflictions affect the viewer projection lens with a further loss in image quality. Finally, screen illumination in the corners is often somewhat lower when viewed from the center. With these factors affecting the image quality, particularly toward the edges, it is not particularly surprising that an observer's attention more or less naturally drifts to a region where he can "see" better.

Fry and Townsend (Ref. 16) found that machine-generated search patterns, using a ring or outline square, which give a complete and uniform coverage are useful primarily when the targets are difficult to find. They also reported that, under good visibility, free search is much preferred. Apparently, under these conditions, peripheral vision plays a significant role and that, on the average, free search represents a faster way of finding a target. The artifical search patterns may serve as a useful training aid, however.

4. FUTURE TASKS

Future areas of investigation will include stereoscopy, flicker, color vision, and fatigue. During the next reporting period, the principal investigator will attend the SPIE conference in New York on "The Human in the Photo-Optical System."

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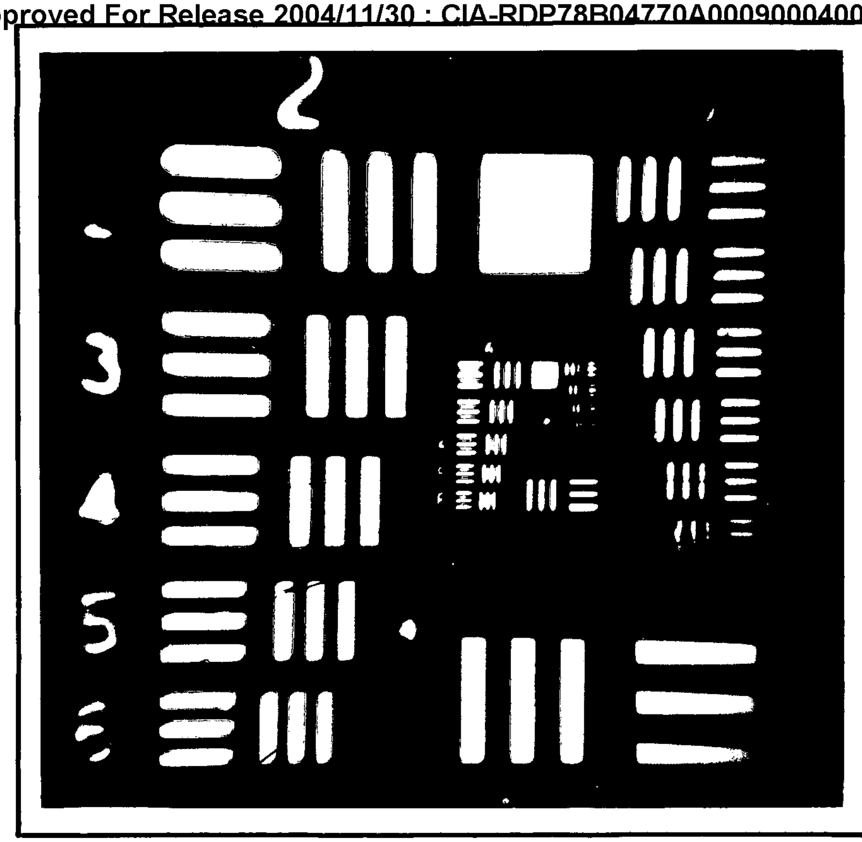

AERIAL IMAGE

IMAGE REFLECTED FROM STATIC ROLLER

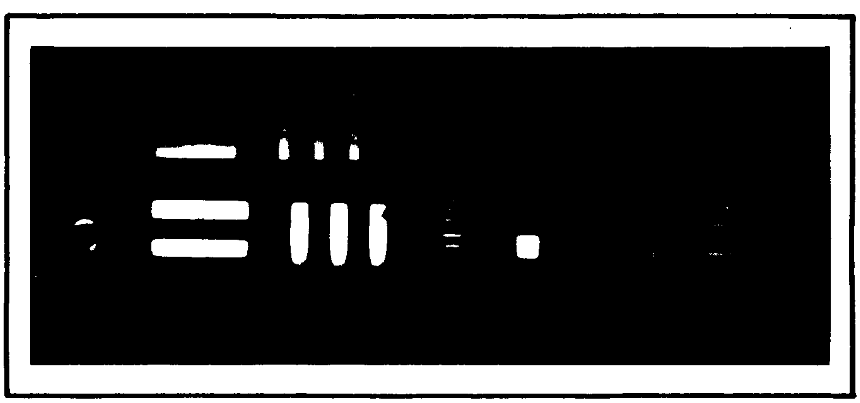

IMAGE REFLECTED FROM ROTATING ROLLER

FIG. 1 – ILLUSTRATION OF GRAIN REDUCTION EFFECTS BY MOVING VIEWING SCREEN

lengths associated with the three color components. Then

$$\sum_{r=1}^{3} a_r(x,y)U_r(t)$$

represents the complex envelope at the space-time point (x,y,t) due to that portion of the beam which has traversed the object, while

$$\sum_{r=1}^{3} \exp[-2\pi i(l+x)\theta\nu_r/c]U_r(t)$$

represents the corresponding complex envelope due to the reference beam. The resultant complex wave amplitude $V(x,y,t)$ at (x,y,t) in the recording plane is therefore

$$V(x,y,t)=\sum_{r=1}^{3}\{a_r(x,y)+\exp[-2\pi i(l+x)\theta\nu_r/c]\} \times U_r(t)\exp(-2\pi i\nu_r t), \quad (1)$$

where ν_1, ν_2, ν_3 are the midfrequencies corresponding to the three primary colors.

Let us now make the usual assumptions that the optical field is stationary, so that all the ensemble averages are time independent, and that there is no second-order coherence between the three color components, so that the average

$$\langle U_r^*(t)U_{r'}(t)\rangle = J_r\delta_{r,r'}. \quad (2)$$

Then the mean light intensity $I(x,y)$ recorded on the photographic plate at the point (x,y) is

$$I(x,y)=\langle V^*(x,y,t)V(x,y,t)\rangle = \sum_{r=1}^{3} J_r\{|a_r(x,y)|^2+1+a_r^*(x,y)\exp[-2\pi i(l+x)\theta\nu_r/c] + a_r(x,y)\exp[2\pi i(l+x)\theta\nu_r/c]\}. \quad (3)$$

After development of the photographic plate this record constitutes the hologram.

Let us suppose that the amplitude transmission of the plate at the point (x,y) after development and reversal is proportional to $I(x,y)$. If the plate is illuminated normally by a 3-color, polarized, plane light beam of the same kind as before, of complex wave amplitude

$$V'(t)=\sum_{s=1}^{3} U_s'(t)\exp(-2\pi i\nu_s t), \quad (4)$$

then the waves emerging at the point (x,y) at time t will have a complex amplitude $V''(x,y,t)$ of the form

$$V''(x,y,t)=\sum_{r=1}^{3}\sum_{s=1}^{3} K_sJ_r[|a_r(x,y)|^2+1]U_s'(t)\exp(-2\pi i\nu_s t)$$
$$+\sum_{r=1}^{3}\sum_{s=1}^{3} K_sJ_ra_r^*(x,y)U_s'(t)\exp\{-2\pi i[\nu_r(l+x)\theta/c+\nu_s t]\}$$
$$+\sum_{r=1}^{3}\sum_{s=1}^{3} K_sJ_ra_r(x,y)U_s'(t)\exp\{2\pi i[\nu_r(l+x)\theta/c-\nu_s t]\}. \quad (5)$$

The complex constants K_1, K_2, K_3 represent transmission coefficients of the hologram for the three primary colors, and probably do not differ too greatly in absolute value.

As is well-known from the analysis of Leith and Upatnieks,[2,3] the terms of the first double summation in Eq. (5) represent plane waves travelling longitudinally, while those of the second double summation represent various reconstructions with phase reversal of the original wavefront, but at an angle to the longitudinal. The terms of the third double summation in Eq. (5) represent the genuine reconstruction of the original wavefront at other angles to the longitudinal, and give rise to the virtual image. In the present case 9 such terms are to be considered. The terms obtained by putting $r=s$ correspond to waves of the three primary colors travelling at an angle θ to the longitudinal, which are correctly

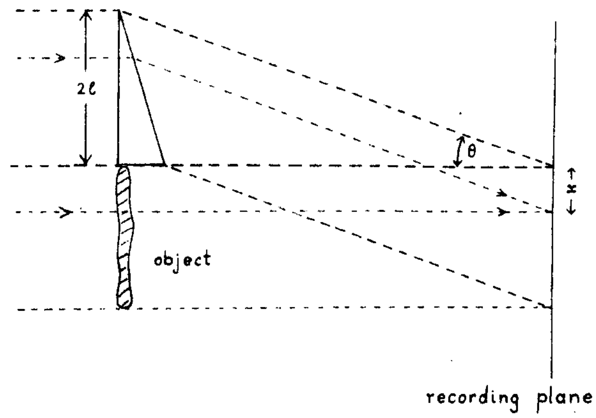

FIG. 1. Optical arrangement for recording holograms.

modulated by the appropriate amplitude transmission function of the original object. Provided $|K_1|$, $|K_2|$, and $|K_3|$ do not differ too much, these three waves allow the virtual image of the object to be seen in true color from a direction θ.

The terms obtained by putting $r\neq s$ in the last double summation of Eq. (5) represent light waves of some color modulated by the amplitude transmission function of the object corresponding to a different color. If these waves were superposed on the previously mentioned ones they would clearly distort the color reproduction process. Fortunately, however, as can be seen from Eq. (5), these waves do not propagate at an angle θ to the longitudinal, but at angles $(\nu_r/\nu_s)\theta$ (with $r\neq s$). Thus, if θ is 30° and if ν_1, ν_2, ν_3 are 4.6, 5.5, 6.7×10^{14} cps, respectively, the angles of propagation are approximately 21°, 25°, 36°, 44°. Hence, provided the view of the virtual image is restricted so as to exclude these directions, there will be no distortion of the color reproduction. In practice the aperture of observation is restricted in any case, and the foregoing restriction is not likely to be serious.

It seems then that the hologram technique of Leith and Upatnieks should be capable of reproducing images in color, substantially without modification.

I am indebted to R. L. Lamberts of the Eastman Kodak Company for a number of discussions of the problems of imaging by the method of wavefront reconstruction.

* Work supported in part by the U. S. Air Force Office of Scientific Research.

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Reduced Graininess of Moving Screens

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(Revision received 22 July 1965)

IT is well-known that graininess on a screen is equivalent to a background noise which deters the observer from extracting a clear impression of an image that is intended to be projected upon the screen. For example, a beaded screen such as is used for the home projection of color slides gives sharper images when the beads are as small as is practical; and a ground glass on a reflex camera is more effective when the surface is prepared in an expert way. In a manner not to be discussed here, the clarity of an image on a grainy screen is a function of the number, size, and distribution of the grains or scattering points over the surface of a screen.

On the assumption that the clarity of images on a screen is determined largely by the effective density of scattering points, some experiments were performed to show that the effective number of points can be increased by changing the positions of the points

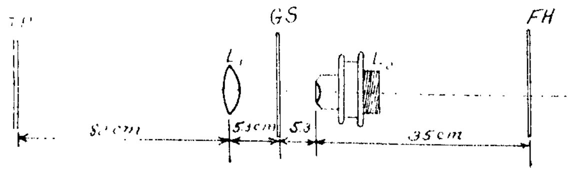

FIG. 1. Arrangement of apparatus.

during a time exposure. This was done by moving the screen on which a stationary image was cast while it was being photographed.

A U. S. National Bureau of Standards test film was placed at

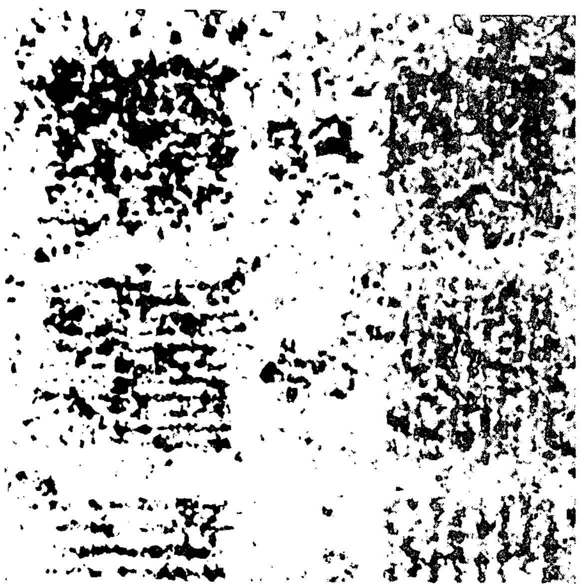

FIG. 2. Enlargement of image on ground glass of Bureau of Standards test film.

IP in Fig. 1 and projected at a reduction of 1/15.4 on a ground glass screen at GS. To see how badly the ground glass resolved the pattern, it was magnified 9.95× onto photographic film at FH. The resultant picture is shown in Fig. 2.

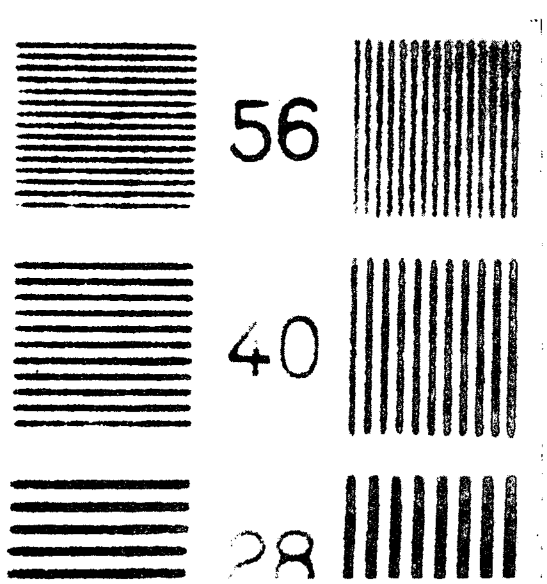

FIG. 3. Enlargement of image on moving ground glass of Bureau of Standards test film.

Then two motors were attached to the ground glass at GS; one moved the screen $\frac{1}{2}$ in. horizontally one revolution per minute and the other moved the glass $\frac{1}{8}$ in. vertically 12 rpm. The total length of path traversed by each point on the screen was about four inches. The resulting picture is shown in Fig. 3.

This experiment suggests that the effectiveness of a viewing screen can be improved by motion. This might be particularly useful for fluorescent screens as used for viewing in the electron microscope or for direct viewing in medical x-ray fluoroscopy. Of course, for direct viewing the motion would have to be produced by high-frequency vibration to smooth out the effect for the human eye.

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Erratum

55, 203 (1965)

TRABKA, E. A. "Wiener Spectrum of Scans Obtained from an Isotropic Two-Dimensional Random Field."

The lower limit of integration in Eq. (3) should be ω instead of 0. Ref. 3 should be J. Acoust. Soc. Am. **16**, 151 (1945).

Book Reviews

Optical Transforms

C. A. TAYLOR AND H. LIPSON. Cornell University Press, Ithaca, New York, 1964. Pp. 182. Price $7.50.

The application of optical transforms to x-ray diffraction problems is presented, by use of the close analogy between the diffraction of x rays and the diffraction of light. This book describes a new research tool for x-ray crystallographers, while illustrating Fourier-transform ideas in general through the visual medium of optical transforms. Two-dimensional models of crystal structures can be made from holes punched in opaque cards (masks). The diffraction pattern of an arrangement of holes representing a single molecule is called the optical transform.

Optical equipment used in diffraction experiments is described, together with the physical and photographic methods of mask preparation. The authors discuss the transformation in both directions between real and reciprocal space. The physical principles of symmetry are illustrated in two dimensions by means of optical diffraction. Fourier synthesis is described for reconstruction of the images from the scattered light waves.

The book is profusely illustrated with figures and photographs which show in detail the use of optical transforms. Fifty-four plates are collected at the center of the book; the complexity and beauty of these photographs clearly demonstrates the essentially physical basis of x-ray crystallography. These photographs should also prove useful to persons engaged in teaching.

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June 1, 1965 G. PARENTI 3,186,299

DEVICE TO INCREASE THE RESOLVING POWER IN PROJECTIONS ON A TRANSLUCENT SCREEN, PARTICULARLY FIT FOR PHOTOGRAMMETRIC APPLIANCES

Filed March 21, 1962

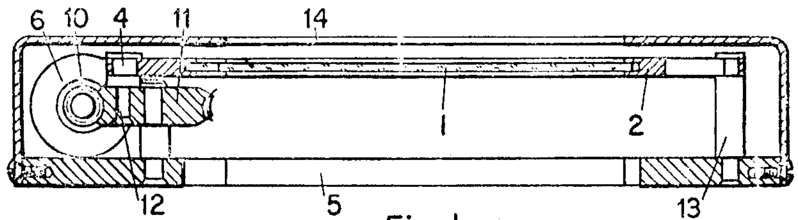

Fig. 1

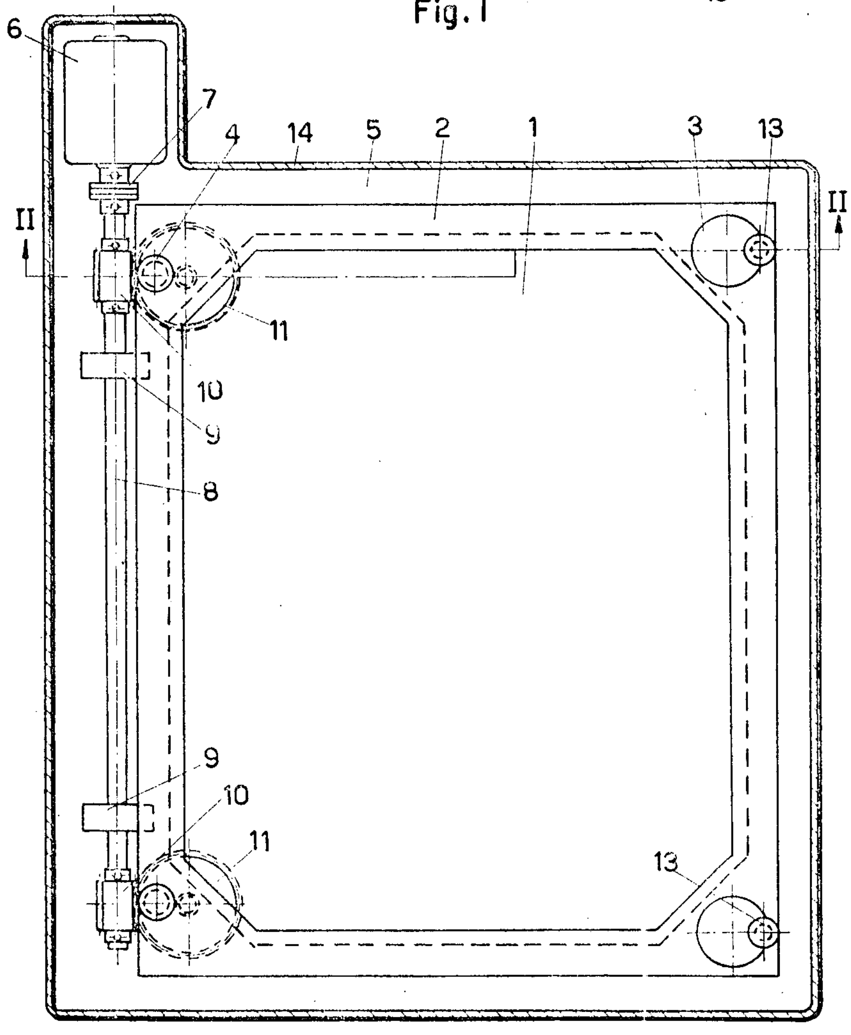

Fig. 2

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United States Patent Office

3,186,299
Patented June 1, 1965

3,186,299

DEVICE TO INCREASE THE RESOLVING POWER IN PROJECTIONS ON A TRANSLUCENT SCREEN, PARTICULARLY FIT FOR PHOTOGRAMMETRIC APPLIANCES

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Filed Mar. 21, 1962, Ser. No. 181,247
Claims priority, application Italy, Mar. 22, 1961, 5,018/61
1 Claim. (Cl. 88—28.93)

There are known in photogrammetric and aerophotogrammetric instrumentations devices for diascopic projection of images on plates or films on a translucent screen, for the purpose of enlarging them properly and, observing them through transparency, to perform on them images of measurements which in this way may reach a high grade precision.

It is therefore necessary to obtain a considerable definition of the projected images, joined to an almost uniform distribution of the luminous intensity of the screen.

It is known that the definition of the projected images is the greater, the more minute the roughness is of the polish constituting the translucent surface on which the image (screen) is formed; on the other hand, however, the possibility of having the optimum of the above-mentioned uniformity of luminous intensity is the greater, the greater within a certain limit, is the roughness of this surface (diffusing capacity of the screen).

The purpose of this invention is to ensure a good definition of the projected images, also to maintain a considerable uniformity of the distribution of the intensity of the illumination of the screen. The description of the invention may more easily be followed in reference to the added illustrating design which represents, by way of a not limited example, a preferred performance. In the illustration:

FIG. 1 represents a screen mounted on a frame;

FIG. 2 is a section of the same according to the hatched plan II—II of FIG. 1.

Referring to the figures a screen is represented with such roughness as to ensure a uniform distribution of the luminosity of the image. Said screen is mounted on frame 2 on the lower end of which are made two holes 3, while at the upper end two pivots 4 are fitted free to turn in their proper seats.

On a supporting plate 5 the motor 6 is fitted of which the turning shaft is made conjoint, by means of a joint 7, with shaft 8 turning in the bearings 9.

In the positions shown in the drawing two endless screws 10 are keyed on shaft 8 in play with as many helicoidal wheels 11. The pivots 4 fitted on frame 2 are clutched in seats 12 eccentrically arranged in the helicoidal wheels 11.

Two pivots 13 are fixed in the holes 3 and made con-

joint with plate 5. The arrangement of pivots 13 and the size of the holes 3, taking into account the eccentricity of pivots 4 with respect to the helicoidal wheels 11, are such as to allow the frame 2 and therefore the formation plan of the projected image, a uniform circular movement of which the trajectory, by virtue of the flanges of pivots 13, constantly will be on the layer located by the above-mentioned collection plan of the projected image.

A cover 14, whilst it protects the mechanical parts in movement, prevents the observer from seeing this, so that the projected image on screen 1 appears to him clear and perfectly defined. In fact, owning to the movement of screen 1, the effect of the roughness of the translucent screen, will be of less influence to the clearness of the image and therefore the image will turn out to admit the relief also in the smallest details. Moreover, the considerable grade of roughness which it was possible to adopt for the translucent surface of the screen, will permit to observe the projected image, endowed by luminous intensity almost uniform from the centre to the margins of the drawing.

The variations of a constructive character which might be applied to the described device will fall into the field of protection of the invention every time that the same inventive conception here exposed would be carried out to reach equal or similar results.

What I claim is:

An optical device, comprising a single translucent screen having a rough surface and adapted to receive a projected image, a frame carrying said screen and having two upper corner portions and two lower corner portions, two symmetrically disposed pivots mounted in said upper corner portions, a supporting plate, a motor carried by said plate, an elongated shaft driven by said motor, two endless screws keyed upon said shaft, two helicoidal wheels meshing with said screws, each of said pivots being eccentrically mounted in a separate helicoidal wheel and being rotatable therewith, said two lower corner portions having circular symmetrically disposed uniform holes, and two pivots mounted in said plate, the two last-mentioned pivots engaging the side walls of said holes and having diameters which are smaller than those of said holes.

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JULIA E. COINER, *Primary Examiner.*

NORTON ANSHER, *Examiner.*

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA
Vol. 53, No. 4, April 1963, p 522

WA20. Granularity of Rear Projection Screens. Vance J. Carpenter, Bausch & Lomb, Inc., 635 St. Paul Street, Rochester 2, New York.

In the conventional use of a rear-projection screen, as exemplified by a contour projector, the observer sees a granular structure which is colored and which moves with the observer's eye. This effect has been found to be dependent upon the numerical aperture of the projection system, and it disappears when the N.A. is large. Results of measurements showing this relationship will be given. A qualitative theory of the cause of this phenomena will be proposed, and a means of eliminating it will be suggested.

APPENDIX A

ARMED FORCES NRC COMMITTEE ON VISION
Membership List

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ARMED FORCES-NRC COMMITTEE ON VISION

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Robert S. Wiseman, PhD Warfare Vision Branch U. S. Army Engineer R & D Labs. Fort Belvoir, Virginia 22060	Recognition and detection capabilities, improvement of night vision
Joseph Zeidner, PhD U. S. Army Personnel Research Office Office of the Chief, R & D Department of the Army Washington, D. C.	Relation of age function to vision standards

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Visibility and search, accommodative-convergence relationships, ocular transmission and retinal burns, all aspects of vision in space flight

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Aircraft exterior lighting, aircraft searchlights

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Use of infra-red photography in evaluating strabismus

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Visual orientation, eye protection, night vision, air crew station lighting

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Photopic and scotopic aspects in relation to U. S. Navy ship design and operation

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Color vision, night vision, temporal factors

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Interaction between the visual and vestibular systems, space perception, evaluation of visual tests, vision as influenced by unusual conditions in orbital and space flight

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Visual standards, protective devices, visual performance

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Temporal factors in vision, eye movement studies, visually evoked cortical potentials and the electroretinogram

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Color vision and organization of the retina, comparative physiology and bio-physics of photoreceptors and associated neural elements, electro-physiology of visual system

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Ophthalmology as applied to aviation-glaucoma, vascular changes in eye, visual standards

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